Field dependence of the Griffith phase in a dilute ferromagnet

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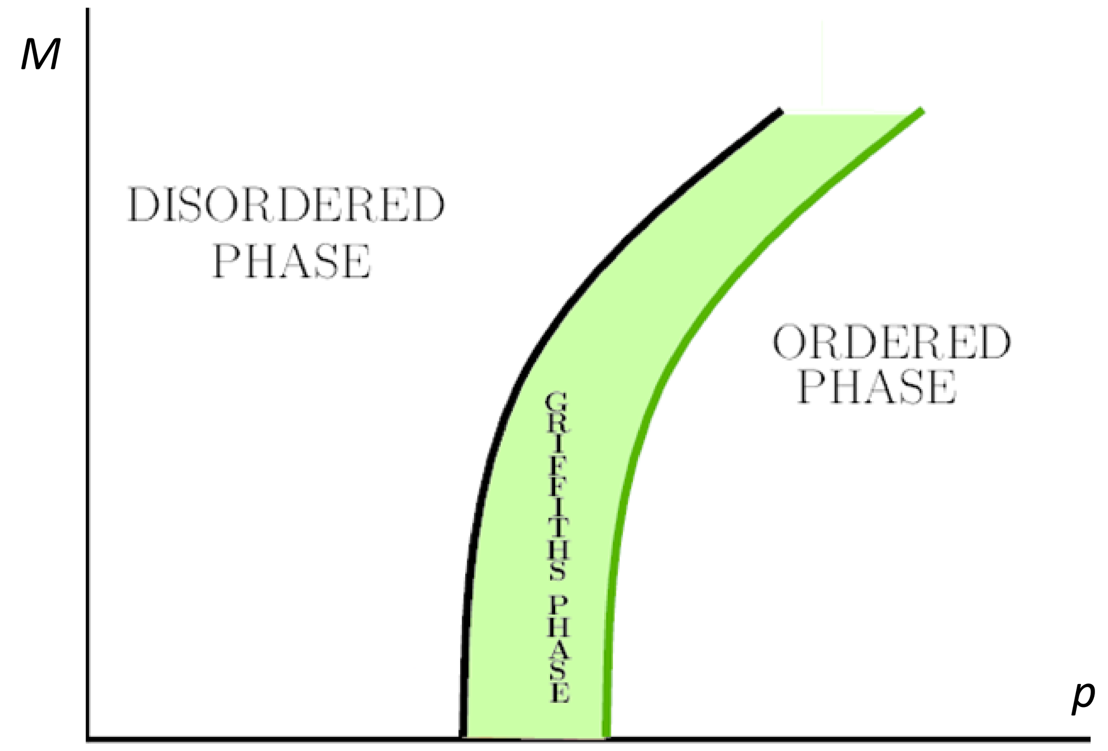
Abstract. In this work, we considered the frozen ferromagnetic Ising model for studying the concentration phase transition. Using the example of a crystalline face-centered cubic lattice, it was shown that random substitution of magnetic atoms for non-magnetic ones leads to a transition to a paramagnetic state even at temperatures close to absolute zero. In this case, nonmagnetic dilution leads to the appearance of an intermediate phase, which is usually called the Griffith phase in the literature. As a result of studying the dependences of magnetic characteristics on the concentration of magnetic atoms in various magnetic fields, we were able to confirm the presence of the Griffith phase.

Introduction

To date, many modern works are devoted to the study of glassy states and materials with ordering similar to the Griffith phase [1-6]. Among such systems, double perovskites Re2CoMnO6 (Re = rare earth ions) attract special attention due to the rich manifestation of semimetallic, semiconductor, magnetic, and piezoelectric properties [6]. At present, it is believed that the manifestation of the listed properties in magnets is conjugated with the Griffith phase. In such a phase, both long-range and short-range orders can exist simultaneously, which will be responsible for various magnetic orderings.



Schematic dependence of the order parameter M (magnetization) on the concentration of magnetic atoms p

In the classical sense, the Griffith phase is a set of ferromagnetic clusters of various shapes and sizes, surrounded by atoms with paramagnetic ordering [7]. Although theoretical studies predict the existence of such a phase, it becomes difficult to register the Griffith phase in direct numerical simulation. In this paper, we report that the anomalous behavior of the magnetic susceptibility observed by us in the Monte Carlo simulation of a diluted Ising ferromagnet indicates the presence of a transition to the Griffith phase. As confirmation of our guesses, we present the results of the analysis of magnetic characteristics calculated in various magnetic fields.

Research methodology

The presence of a phase transition was determined from the position of the maximum of the magnetic susceptibility χ calculated from the well-known formula (1) and the behavior of the magnetization M (2). Here N is the number of nodes in the lattice; t – relative temperature; brackets $\langle\ \rangle$ and [ ] denote averaging over 10^4 Monte Carlo steps and 10^3 different lattice configurations, respectively.

$$\chi = \frac{N}{t}\left[\langle M^2\rangle - \langle M\rangle^2\right], \qquad (1)$$

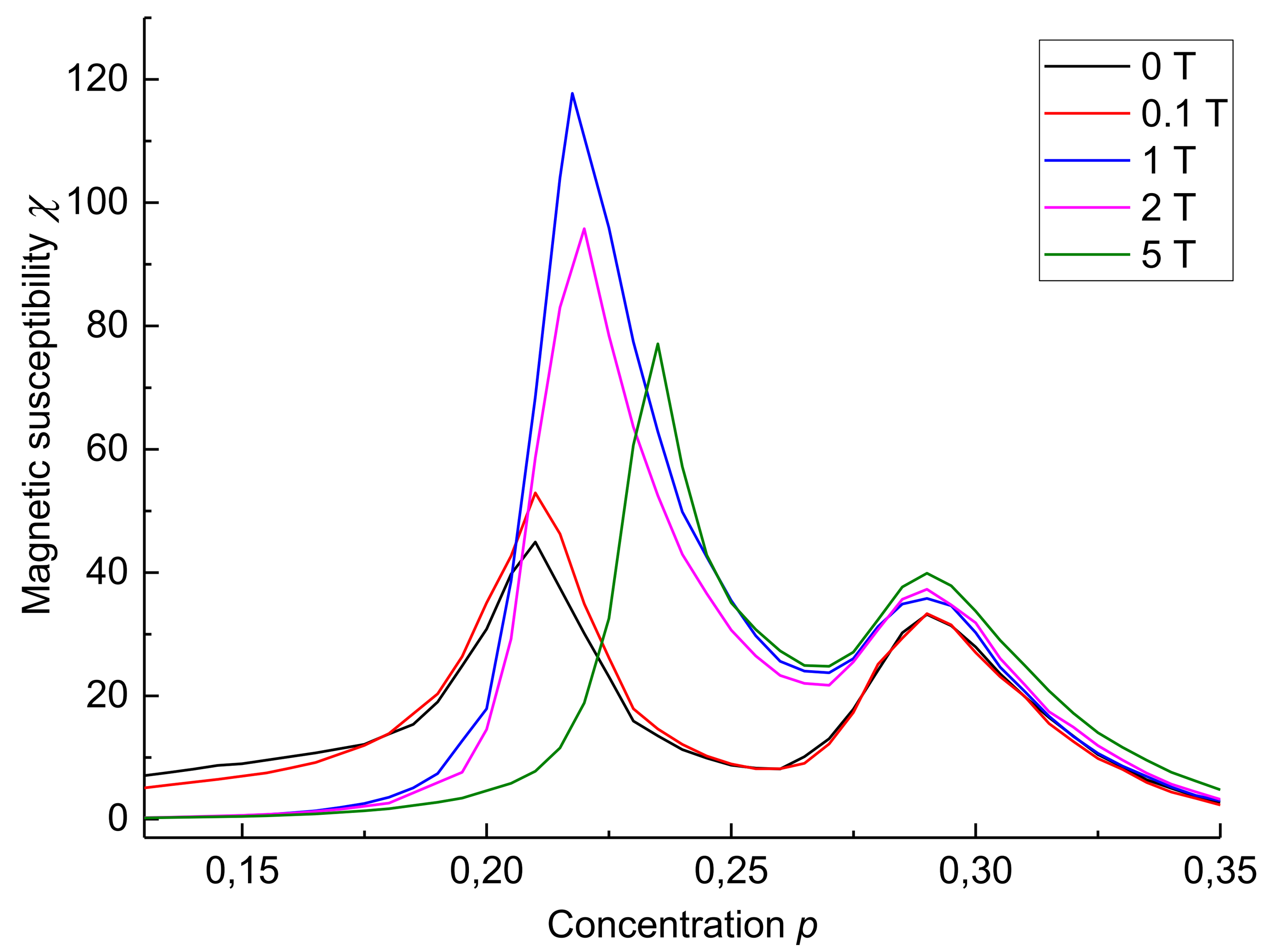
$$M_{ma} = \frac{1}{N}\left[\left\langle \sum_{i}^{N_m} s_i \right\rangle\right], \qquad (2)$$

$$\mathcal{H} = -J\left(\frac{1}{2}\sum_{\{i,j\}} c_i c_j s_i s_j + h\sum_i c_i s_i\right), \qquad (3)$$

The calculation was carried out at a temperature close to absolute zero $t=0.01$. The Hamiltonian was determined by expression (3), where J is the exchange

Where s is the spin variable of the magnetic moment at the i-th site of the lattice, and $c = 0$ or 1 if the site is occupied by a non-magnetic or magnetic atom.

Results and discussions

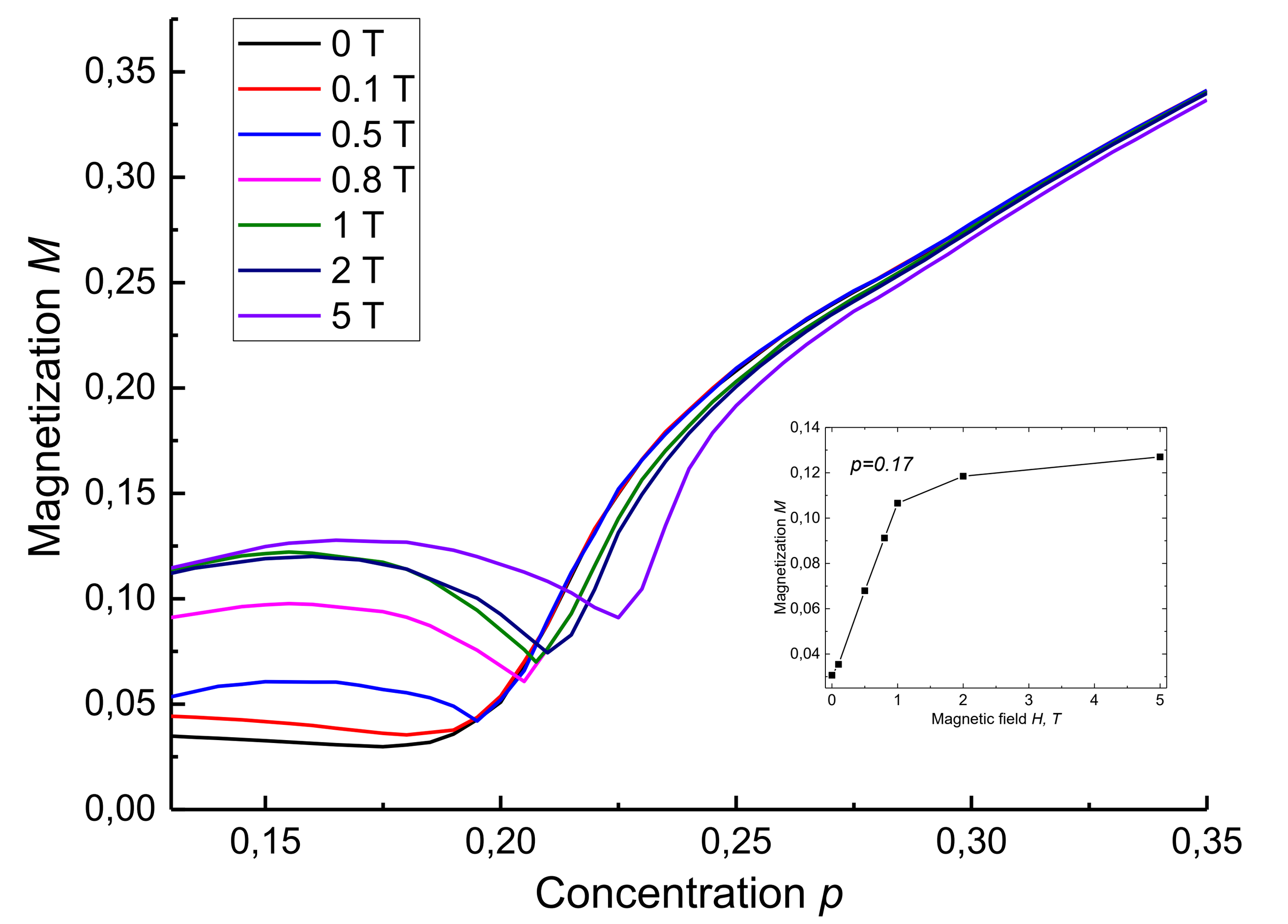


Dependence of the magnetic susceptibility χ on the concentration of magnetic atoms p in various magnetic fields h

The anomalous behavior of the magnetic susceptibility, which manifests itself in two maxima (Figure 1), is interpreted as a manifestation of two successive phase transitions. Similar anomalies are observed both in the magnetization [1-3], and in the susceptibility [2-4] and heat capacity [5] of real systems. Thus, we believe that the high-concentration peak $p_{c,h}$ corresponds to the transition from the ferromagnetic phase to the Griffith phase, and the low-concentration $p_{c,l}$ to the paramagnetic phase from the Griffith phase. In the region between $p_{c,h}$ and $p_{c,l}$, a state is observed in which the magnetization remains high due to the existence of large ferromagnetic clusters. At the same time, fluctuations grow, and the magnetization vanishes due to the division of such clusters into many small ones. Thus, the Griffith phase is represented by the cluster and spin glass phases.

Indeed, the behavior of the magnetization and magnetic susceptibility at different magnetic fields indicates the existence of a glassy state. A sign is the dependence of the magnetization on the magnetic field near the critical point and the shift of the maximum corresponding to the paramagnetic point of the phase transition (Figure 2).

It should be noted that the high-concentration peak does not change its position. This is explained by the fact that the transition from the ferrimagnetic state to the Griffith phase is accompanied by the breaking of an infinite cluster and the appearance of unbound large clusters. And although there is no interaction between them, the ferromagnetic order is preserved within each individual cluster. This explains the relatively high residual magnetization. At the same time, the magnetic field can in no way affect even the boundaries of such large clusters. For the phase transition to the Griffith phase, this behavior corresponds to the experimental data [2].



Dependence of magnetization M on the concentration of magnetic atoms p in various magnetic fields h. The inset shows the increase in magnetization with an applied field near the paramagnetic phase transition $p_{c,l}$.

Conclusions

Nonmagnetic dilution of the ferromagnetic Ising model leads to two successive phase transitions: ferromagnet – Griffith phase and Griffith phase – paramagnet. Two such phase transition points can be considered as ferromagnetic and paramagnetic, where the paramagnetic point, as expected, depends on the magnetic field. In this case, the transition point to the Griffith phase remains unchanged, as do the fluctuations of the magnetic order parameter at different fields, which confirms the presence of a transition to the cluster glass state.

References

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